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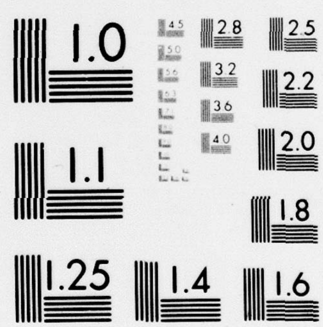


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# REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: M 15/79
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): (6) Reproducibility of Onset and Sensitivity of Sweating During Exercise at Thermoneutrality,
5. TYPE OF REPORT & PERIOD COVERED: (9) NA
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): (10) Donald Horstman, ~~Ph.D.~~ ~~and~~ Omar Hottenstein
8. CONTRACT OR GRANT NUMBER(s): (12) 16
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Research Institute of Environmental Medicine, Natick, Massachusetts 01760
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 6.11.02.A Defense Research Sciences, Army 3E161102BS08 94102005 (16)
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Medical Research and Development Command, Ft. Detrick, Frederick, MD 21701 (11)
12. REPORT DATE: 26 June 1979
13. NUMBER OF PAGES: 12
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Same
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

LEVEL II

16. DISTRIBUTION STATEMENT (of this Report): Distribution of this document is unlimited.



17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report): NA (14) USARIEM-M-15/79
18. SUPPLEMENTARY NOTES: NA
19. KEY WORDS (Continue on reverse side if necessary and identify by block number): sweat onset, sweat sensitivity, esophageal temperature, exercise, reliability, circadian variation.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
The reproducibility of a test of thermoregulatory function was examined. Active male volunteers cycled at 70% $\dot{V}O_2$ max at 25°C, 20% relative humidity. Chest sweat rate ($\dot{m}_{sw}$), measured by resistance hygrometry, and Tes were recorded. By plotting $\dot{m}_{sw}$ as a linear function of Tes, Tes for onset of sweating (onset) and increase of $\dot{m}_{sw}$ per °C rise of Tes (sensitivity) were ascertained. Tests were performed daily at the same time on 3 consecutive days (n = 6); at 0800, 1000, 1200, 1400 and 1600 hours on 5 different days (n = 5); and at 0800, 1030, 1300 and 1530 hours on the same day (n = 5).

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Repeated measures analysis of variance for each experimental protocol revealed no statistically significant differences for onset or sensitivity. Test-retest coefficients of correlation for both onset and sensitivity comparing any 2 test days or any 2 test times were in excess of 0.90 and 0.85, respectively. It is concluded that results from this test are reproducible from day to day and are relatively insensitive to time of administration (within the limits 0800 to 1600 hours). Moreover, prior testing on the same day dows not influence results obtained from testing later in the day.

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# Reproducibility of Onset and Sensitivity of Sweating during Exercise at Thermoneutrality

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Running Title: Reproducibility of Sweat Measures

## Abstract

The reproducibility of a test of thermoregulatory function was examined. Active male volunteers cycled at 70% $\dot{V}O_2$ max at 25°C, 20% relative humidity. Chest sweat rate ($\dot{m}_{sw}$), measured by resistance hygrometry, and Tes were recorded. By plotting $\dot{m}_{sw}$ as a linear function of Tes, Tes for onset of sweating (onset) and increase of $\dot{m}_{sw}$ per °C rise of Tes (sensitivity) were ascertained. Tests were performed daily at the same time on 3 consecutive days (n = 6); at 0800, 1000, 1200, 1400 and 1600 hours on 5 different days (n = 5); and at 0800, 1030, 1300 and 1530 hours on the same day (n = 5). Repeated measures analysis of variance for each experimental protocol revealed no statistically significant differences for onset or sensitivity. Test-retest coefficients of correlation for both onset and sensitivity comparing any 2 test days or any 2 test times were in excess of 0.90 and 0.85, respectively. It is concluded that results from this test are reproducible from day to day and are relatively insensitive to time of administration (within the limits 0800 to 1600 hours). Moreover, prior testing on the same day does not influence results obtained from testing later in the day.



Key words: sweat onset, sweat sensitivity, esophageal temperature, exercise, reliability, circadian variation.

Nadel *et al.* (6) have described a test to determine onset and sensitivity of sweating as functions of increasing esophageal temperature during exercise in a thermoneutral environment. Since this testing is conducted at thermoneutral ambient temperature, it allows evaluation of sweating function independent of degree of external heat stress and offers the potential for repeated testing at short time intervals without the complicating influences of heat acclimatization. Data relative to reproducibility of results from this test are lacking. Circadian variations in results obtained have been suggested specifically for this test, however comparisons were made only between experiments conducted at night and during the day (9). The purposes of the present study were to evaluate the day to day reproducibility (reliability) of the test; to determine the pattern of circadian variations during a limited portion of the day (0800 - 1700 hours), a time frame within which experimental testing is normally conducted; and to determine if prior testing on the same day influences results obtained from testing later in the day.

## Methods

Six active male volunteers, who were not heat acclimatized, served as subjects for these experiments. Their mean $\pm$S.E. age, height and weight were $24.0 \pm 2.0$ years, $177.4 \pm 3.1$ cm and $73.4 \pm 2.7$ kg, respectively. Each volunteer was fully informed of the purposes, experimental protocol and procedures of the experiments, as well as potential risk from participation; and each signed a statement of informed consent.

Maximal oxygen consumption ($\dot{V}O_2$ max) was determined for each subject on the bicycle ergometer by an interrupted procedure similar to that described

by McArdle et al. (3). Briefly, this procedure required the subject to cycle for five minutes at three submaximal exercise intensities and to exhaustion (< 5 min) at two maximal exercise intensities, with rest between each exercise period. Oxygen consumption ($\dot{V}O_2$), heart rate (HR) were determined near the end of each work period. The criterion for $\dot{V}O_2$ max was a plateauing of $\dot{V}O_2$, concomitant with increased exercise intensity. Subjects breathed through a Collin's Triple - J valve, and expired air passed through a mixing chamber and turbine spirometer. Gases in the mixing chamber was continuously sampled for determination of fraction expired $O_2$ with a fuel cell $O_2$ analyzer and for fraction expired $CO_2$ with an infrared $CO_2$ analyzer. Appropriate corrections for barometric pressure and temperature were made to calculate $\dot{V}_E$ (STPD) and $\dot{V}O_2$ was calculated by the Haldane formula. Heart rate was measured from ECG tracings as ECG was monitored continuously throughout these tests. From $\dot{V}O_2$ measurements during submaximal exercise, relative intensities approximating 70% $\dot{V}O_2$ max were derived for further experiments.

Prior to each test for onset and sensitivity of sweating, subjects rested in the chamber at least 30 min before exercising. Subjects were attired only in shorts, socks and tennis shoes. To establish esophageal temperature (Tes) for sweating onset and change of sweat rate per $^{o}$C rise of Tes (sensitivity), subjects cycled for 8 to 15 min at approximately 70% $\dot{V}O_2$ max. Mean ambient temperature was 25$^{o}$C (range 24 to 26$^{o}$C); relative humidity was approximately 20%. Tes was measured at 30 sec intervals with a copper-constantan thermocouple at heart level in the esophagus. Skin temperatures from the chest (Tch), lateral upper arm (Tarm) and anterior thigh (Tth) were measured at 30 sec intervals with copper-constantan thermocouples; mean skin temperature ($\bar{T}_{sk}$) was calculated according to Roberts et al. (7) as:

$$\bar{T}_{sk} = 0.43\ Tch + 0.25\ Tarm + 0.32\ Tth$$

Sweating was continuously recorded by resistance hygrometry from a 12 $cm^2$ sweat capsule on the chest over the seventh and eighth ribs in the mid-clavicular line. This site was marked with a pen to aid in maintaining the site of sweating measurements constant for all of the testing. This procedure, described in detail by Nadel et al. (4), consists of passing an air stream (constant water content and flow rate) over the encapsulated area of the skin and measuring the change of water content of the air. Sweat rate ($\dot{m}_{sw}$), in mg/min $\cdot$ $cm^2$, was calculated at 30 sec intervals as:

$$\dot{m}_{sw} = \dot{F} \cdot 0.01\ \Delta\ RH \cdot {}^{1}/D \cdot {}^{1}/12\ cm^2, \text{ where}$$

$\dot{F}$ = rate of air flow through capsule (ml/min)

$\Delta$ RH = difference in relative humidity between air entering and leaving capsule (%), and

D = density of saturated steam at RH measurement temperature (mg/ml).

From linear plots of $\dot{m}_{sw}$ as a function of Tes, Tes for sweating onset was derived as the 0 $\dot{m}_{sw}$ intercept and sweat sensitivity as the slope of the line. Heart rate was measured at 5 min intervals from ECG tracings, as ECG was monitored periodically throughout these tests.

To ascertain the reliability of this test, subjects performed the test daily for three consecutive days; each subject performed the test at the same time each day. To determine circadian variations, subjects performed the test once daily on five different days at 0800, 1000, 1200, 1400 and 1600 hours. To determine if prior testing on the same day influences results from testing

performed later in the day, subjects performed the test at 0800, 1030, 1300 and 1530 hours on the same day.

## Results

The mean ±S.E. $\dot{V}O_2$ max for the six subjects tested in this study was 3.61 ± 0.50 liters/min or 49.1 ±1.8 ml/kg • min; mean ±S.E. maximal HR was 185 ±3 beats/min. For the sweating tests, bicycle exercise was performed at a mean ±S.E. intensity of 975 ± 45 KPM/min. Estimated $\dot{V}O_2$ for this exercise was 2.56 liters/min this corresponds to a mean relative exercise intensity of 71% $\dot{V}O_2$ max. One subject withdrew from the study following reliability testing; the means and S.E. of the previous parameters were not altered by his withdrawal.

Table 1 depicts results from sweating tests performed daily on three consectuive days. In this and subsequent tables, Heart Rate is the mean for all subjects measured at 5 min, while $\bar{T}_{sk}$ is the mean for all measures of $\bar{T}_{sk}$ throughout the exercise. One-way repeated measures analysis of variance revealed no statistical differences for any of the measures during the three test days. Test-retest coefficients of correlations for sweat onset and sensitivity comparing any two combinations of test days were in excess of 0.90.

Results from tests performed at different times on different days are presented in Table 2. One-way repeated measures analysis of variance revealed no statistical differences for any of the measures for any time of day. Although not statistically different, Tes for sweat onset was lower at 0800 than at any other time. Test-retest coefficients of correlation for sweat onset and sensitivity comparing any two combinations of test times were in excess of 0.85.

Finally, Table 3 presents comparative results from tests performed at different times on the same day. Again, no statistical differences for any of the measures for any time of day were indicated by one-way repeated measures analysis of variance. Again, although not statistically different, Tes for sweat onset was lower at 0800 than at any other time. Test-retest coefficients of correlation for sweat onset and sensitivity comparing any two combinations of test times were also in excess of 0.85.

## Discussion

Nadel et al. (6) have described a method to determine threshold and sensitivity for sweating as a function of increasing esophageal temperature during exercise in a thermoneutral environment. This method is sensitive to both physical training and heat acclimatization and offers some distinct advantages over the more commonly used methods (heat exposure with or without exercise) for evaluating sweating responses. The time to administer the test is quite short, requiring only about 30 minutes. Procedures are relatively simple, requiring equipment of minimal sophistication. Testing is conducted at thermoneutral ambient temperature (25°C) allowing evaluation of thermoregulatory function independent of degree of external heat stress and offering the potential for repeated testing at short time intervals without the complicating influences of heat acclimatization.

It is our intent to use this test as a primary criterion for prediction of exercise performance in the heat in large populations. As such, we were especially concerned with the reproducibility of results obtained from naive subjects. In previous studies, in which this test, or some facsimile thereof, was

utilized, reliability was either assumed and a single test performed (5), or duplicate tests were performed (6,7,9). We considered a formal evaluation of the day to day reproducibility of results obtained from this test was warranted. Our results indicate that Tes for onset of sweating and sweat sensitivity were reproducible from day to day.

Previous investigators (1,2,8) have reported that during early morning exposures to heat without exercise, subjects began sweating at lower rectal, tympanic or mean body temperatures than during the same exposure in late morning, afternoon or evening. For the specific test which we evaluated Wenger et al. (9) observed Tes for sweat onset to be lower between 0400 and 0530 hours as compared to that observed between 1200 and 1630 hours. No difference in sweat sensitivity was observed between early morning and afternoon. Our interests were in reproducibility of results within a time frame which we normally conduct experimental testing. Our results indicate that Tes for onset of sweating and sweat sensitivity were insensitive to time of day within the limits 0800 through 1600 hours. This was true whether tests were administered on different or the same day, as prior testing on the same day did not influence results obtained from testing later in the day. It should be noted that Tes for onset of sweating tended to be lower at 0800 and, as a precaution, it is recommended that testing not be conducted prior to 0900 hours.

Acknowledgment

The authors are indebted to Elaine Christensen for her excellent technical assistance.

Footnotes

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2. The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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Table 1. Sweat Onset and Sensitivity (Mean $\pm$ S.E.) for Tests Performed at the Same Time on Three Consecutive Days (n = 6 )

| | Heart Rate Beats/min | $\bar{T}_{sk}$ $^{o}C$ | Sweat Onset $^{o}C$ | Sweat Sensitivity $mg/cm^{2} \cdot min/^{o}C$ |
|---|---|---|---|---|
| Day 1 | 142 $\pm$ 3 | 32.4 $\pm$ 0.2 | 37.24 $\pm$ 0.13 | 0.82 $\pm$ 0.11 |
| Day 2 | 144 $\pm$ 4 | 32.7 $\pm$ 0.2 | 37.27 $\pm$ 0.12 | 0.78 $\pm$ 0.12 |
| Day 3 | 144 $\pm$ 4 | 32.5 $\pm$ 0.3 | 37.34 $\pm$ 0.13 | 0.76 $\pm$ 0.11 |

Table 2. Sweat Onset and Sensitivity (Mean $\pm$ S.E.) for Tests Performed at Different Times on Different Days (n = 5).

| Time | Heart Rate Beats/min | $\bar{T}_{sk}$ $^{o}C$ | Sweat Onset $^{o}C$ | Sweat Sensitivity $ms/cm^2 \cdot min/^{o}C$ |
|---|---|---|---|---|
| 0800 | 144 $\pm$ 2 | 32.5 $\pm$ 0.2 | 37.13 $\pm$ 0.09 | 0.68 $\pm$ 0.07 |
| 1000 | 143 $\pm$ 3 | 32.4 $\pm$ 0.2 | 37.25 $\pm$ 0.09 | 0.70 $\pm$ 0.09 |
| 1200 | 146 $\pm$ 5 | 32.3 $\pm$ 0.2 | 37.22 $\pm$ 0.12 | 0.68 $\pm$ 0.08 |
| 1400 | 146 $\pm$ 3 | 32.5 $\pm$ 0.2 | 37.27 $\pm$ 0.08 | 0.68 $\pm$ 0.10 |
| 1600 | 146 $\pm$ 3 | 32.6 $\pm$ 0.3 | 37.29 $\pm$ 0.09 | 0.70 $\pm$ 0.10 |

Table 3. Sweat Onset and Sensitivity (Mean $\pm$ S.E.) for Tests Performed at Different Times on the Same Day (n = 5).

| Time | Heart Rate Beats/min | $\bar{T}_{sk}$ °C | Sweat Onset °C | Sweat Sensitivity $mg/cm^2 \cdot min/°C$ |
|---|---|---|---|---|
| 0800 | 144 $\pm$ 2 | 32.5 $\pm$ 0.2 | 37.13 $\pm$ 0.09 | 0.68 $\pm$ 0.07 |
| 1030 | 145 $\pm$ 2 | 32.6 $\pm$ 0.2 | 37.22 $\pm$ 0.06 | 0.66 $\pm$ 0.09 |
| 1300 | 146 $\pm$ 3 | 32.5 $\pm$ 0.2 | 37.26 $\pm$ 0.06 | 0.71 $\pm$ 0.08 |
| 1530 | 148 $\pm$ 3 | 32.4 $\pm$ 0.2 | 37.23 $\pm$ 0.09 | 0.72 $\pm$ 0.08 |